Docket No. P-5231CIP

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION FOR UNITED STATES LETTERS PATENT

INVENTORS: Jeffrey A. ZIMMERMAN
16271 Kettle River Blvd.
Forest Lake, MN 55025
U.S.A.

Ralph H. LARSON
474 South Fifth Street
Bayport, MN 55003
U.S.A.

Paul C. MYHRE
6872 Ashwood Road, #206
Woodbury, MN 55125
U.S.A.

TITLE: CONTROLLER FOR SALT DOSAGE FOR A WATER SOFTENER AND METHOD OF REGENERATING A WATER SOFTENER

ATTORNEY: David J. Richter
PIPER MARBURY RUDNICK & WOLFE
P.O. Box 64807
Chicago, Illinois 60664-0807
(312) 368-4000

CONTROLLER FOR SALT DOSAGE FOR A WATER SOFTENER and METHOD OF REGENERATING A WATER SOFTENER

This application is a continuation in part of U.S. application serial number 09/016,203, filed January 30, 1998.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the art of water softening systems. More particularly, the present invention is directed to a method and apparatus for the efficient use of potassium chloride as the regenerant in a water softener.

2. Description of Related Art

A number of different methods and systems are known in the art for softening water. The water softening process involves the replacement of "hard" ions, such as calcium and magnesium, with "soft" ions such as sodium and potassium. Soft water is often desirable because it is less likely to leave deposits on plumbing fixtures.

Water softeners typically utilize an ion exchange material, typically present as a resin bed, to soften water. In the water softening process untreated water is brought into contact with the resin bed where "hard" ions are exchanged for "soft" ions to provide a source of softened water. After prolonged contact with untreated water, however, the capacity of the resin bed to soften water becomes exhausted. When this occurs, the resin bed may be regenerated by exposing it to a brine solution containing the desired "soft" ions, which process restores its water softening capacity.

The brine needed for regeneration may be formed by dissolving in a quantity of water a regenerant salt having the desired "soft" ions. Typical regenerant salts are sodium chloride and potassium chloride. The type of regenerant salt used determines what type of "soft" ions will be present in the softened water. In particular, sodium chloride results in sodium ions being introduced into the softened water, and potassium chloride results in potassium ions being introduced into the softened water.

Many water softeners regenerate the resin bed automatically. In such systems the resin bed is in service most of the time softening water. When the water softener system determines that regeneration is required, it stops softening water and instead regenerates the resin by exposing it to the brine. A number of different methods are known for automatically determining when to initiate a regeneration. Some of these methods are described in U.S. Patent Nos. 5,544,072 and 4,722,797, which are incorporated herein by reference. Typically, in such methods, regenerations are performed before the resin bed is completely exhausted, in order to ensure that the user does not run out of soft water.

In addition to determining when to regenerate, many systems automatically select the amount of regenerant to be used in a regeneration step. The regenerant is often provided in the form of dry regenerant salt located in a vessel separate from the resin bed, termed the "brine tank." A measured amount of water is introduced into the brine tank in order to dissolve the desired amount of regenerant, forming a brine. Typically, the rate at which water enters the brine tank, the "fill rate," is fixed, so that the fill time determines the amount of water introduced and therefore the amount of regenerant salt dissolved. The brine is then transferred from the brine tank to the resin bed, so that

the resin bed is exposed to a known amount of regenerant during the regeneration process. The used brine is then disposed of as waste.

Sodium chloride (NaCl) has been the regenerant salt most commonly used in water softeners. However, the use of potassium chloride (KCl) as the regenerant is an attractive alternative. The potassium ions added to soft water from softeners regenerated with KCl are more beneficial to human health as well as to plant life than the sodium ions added to soft water from softeners regenerated with NaCl. The use of KCl as the regenerant also often results in less chloride being present in the waste brine, making its disposal less environmentally damaging.

Most water softeners, however, are designed for NaCl regenerant and lack the flexibility to operate adequately if KCl is used as the regenerant instead. In particular, if KCl is used as the regenerant, the resin bed may become exhausted prematurely, i.e., before it is regenerated. As a result, the user would run out of soft water. The problem becomes more acute as a function of water temperature and softener efficiency, i.e., the colder the water is that is used to form the brine and the more efficiently the water softener uses regenerant salt, the more likely premature exhaustion is.

Moreover, the use of KCl as the regenerant is more complicated than the use of NaCl for a number of reasons. First, in certain operational regimes, namely, when the resin bed is used most efficiently, the resin bed requires a greater amount of KCl than NaCl for regeneration. Second, the solubility of KCl in water is highly temperature dependent, unlike NaCl. In particular, the solubility of KCl in cold water is greatly reduced relative to NaCl. As a result, when cold water is used to form the brine, a greater amount of water is required to dissolve the KCl. Third, the dissolution of KCl in water is significantly endothermic, so that the KCl cools the water as it dissolves, thereby lowering its solubility even more. Finally, KCl dissolves in water at a slower rate than NaCl.

U.S. Patent Nos. 5,544,072 and 4,722,797 each disclose a method and apparatus for operating a water softener. These references also disclose that either potassium chloride or sodium chloride may be used as the regenerant, but they do not suggest any changes to the water softening method or apparatus depending on whether NaCl or KCl is used. Such changes are required, however, because of the different characteristics of these two salt types. As a practical matter, then, water softeners in accordance with these references do not have the flexibility to be able to use either NaCl or KCl at the option of the user. Moreover, these references do not disclose any way of accounting for the more complicated characteristics of KCl, such as its temperature dependent solubility, in order to use KCl as a regenerant in an efficient and reliable manner.

SUMMARY OF THE INVENTION

The principal object of the present invention is to provide a water softener and a method of operating the same to allow for the efficient and reliable use of KCl as the regenerant salt.

Another object of the present invention is to provide a water softener method and apparatus having the flexibility to allow either NaCl or KCl to be used as the regenerant salt at option of the user.

Yet another object of the present invention is to provide a method and apparatus for filling the brine tank of a water softener to account for changes in the brine temperature occurring during the course of the fill and thereby to ensure that the required amount of regenerant salt is dissolved.

In accordance with the present invention, a water softener and a method of operating the same are provided to allow for the efficient and reliable use of either NaCl or KCl as the regenerant salt. A user interface is provided to allow the user to indicate to the computer controlling the water

softener whether NaCl or KCl is being used. The computer controller adjusts the fill time and brine time depending on the type of regenerant salt used. The temperature of the brine is measured at regular intervals as water is being supplied to the brine tank to dissolve the KCl. At each interval the computer calculates the amount of water needed to dissolve the required amount of KCl, and the fill ends when the amount of water added is approximately equal to the required amount calculated at the most recent time interval.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a graph which illustrates curves representing the capacity of a typical resin bed as a function of the salt dosage used to regenerate it. The solid line corresponds to the use of NaCl as the regenerant, and the dotted line corresponds to the use of KCl.

FIG. 2 is a schematic representation of an automatic water softener in accordance with the present invention.

FIG. 3 is a schematic representation of a user interface for the water softener in accordance with the present invention.

FIG. 4 is a graph showing the relationship between brine temperature and the water volume equivalency of KCl with respect to NaCl.

FIG. 5 is a graph showing the relationship between brine temperature and the water volume adjustment rate to obtain equivalent amounts of KCl in solution.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Water hardness is typically expressed in terms of grains per gallon, which represents the weight in grains of calcium carbonate ($CaCO_3$) which would be needed to be dissolved in one gallon of water to achieve that level of hardness. The capacity of a resin bed, which represents the amount of water of a given hardness it can soften before becoming exhausted, is therefore expressed in grains as follows:

$$C = H \times V$$

where C = capacity of the resin bed in grains, H = the hardness of the water in grains per gallon, and V = the amount of water in gallons at that hardness that can be treated by the resin bed before exhausting it.

When the resin bed becomes exhausted, it may be regenerated by exposing it to a brine comprising a quantity of regenerant salt dissolved in water. The salt dosage, dissolved in water as a brine, required to regain the desired capacity depends on the efficiency of the resin bed. The efficiency, E, of a resin bed is defined as follows:

$$E = C/D$$

where D = the dosage of regenerant salt applied to the resin bed in pounds, and C = the capacity of the resin in grains resulting from that salt dosage.

The water softening process, to the extent that it involves the removal of calcium ions, involves the exchange of either two Na^+ ions or two K^+ ions for one Ca^{2+} ion. Since the molecular weights of $CaCO_3$, KCl, and NaCl are 100.09, 74.56, and 58.44, respectively, and since 1 pound = 7000 grains, the theoretical efficiency is 5995 grains/lb. when NaCl is used and 4699 grains/lb. when KCl is used. Theory thus predicts that NaCl is 28% more efficient as a regenerant salt than KCl,

with the result that more KCl would be required for regeneration in order to achieve the same capacity.

In practice, however, resin beds approach their theoretical efficiencies only when low salt dosages are used. The reason for this is that the capacity cannot be increased without limit by increasing the salt dosage. With higher salt dosages, the resulting capacity levels off and gradually approaches a limiting value. Put another way, as the salt dosage is increased, the efficiency falls increasingly below its theoretical value. Moreover, it has been found that for sufficiently high salt dosages, the amount of NaCl and KCl needed to achieve the same capacity becomes essentially the same.

This general trend is illustrated schematically in Figure 1, which is a graph of the capacity of a typical resin bed in grains as a function of NaCl and KCl dosage in pounds. The NaCl curve is a solid line, and the KCl curve is a dotted line. As shown in that graph, when low salt dosages are used, NaCl results in a greater capacity than the same dosage of KCl. However, with higher salt dosages the resulting capacity becomes nearly independent of the type of salt used.

Many water softeners operate in the regime where NaCl and KCl have nearly the same efficiency. However, a more efficient use of regenerant salt is obtained by using lower salt dosages, albeit at the cost of more frequent regeneration. In this regime, then, the lower efficiency of KCl, as compared to NaCl, must be compensated for by increasing the KCl dosage during regeneration.

Preferably, curves for KCl and NaCl like those in Figure 1 are generated for each resin bed to determine the salt dosage required to achieve the desired capacities. Such data is typically obtained by exhausting the resin bed until the effluent water has a hardness of one grain per gallon.

The resin bed is then regenerated with a regenerant brine having a selected salt dosage. Water of a known hardness is passed through the resin bed until the effluent water reaches a hardness of one grain per gallon. The amount of water that has passed through the resin bed is measured, and from this quantity the capacity of the resin bed may be calculated.

This procedure is then repeated for various salt dosages to generate the curve of capacity versus salt dosage as in Figure 1.

An automatic water softener **10** adapted to use potassium chloride in accordance with the present invention is shown schematically in Figure 2. When water softener **10** is "in service" it is designed to treat hard water to provide a source of soft water. Periodically, water softener **10** automatically goes out of service, thereby ceasing the softening of water, and enters a "regeneration cycle" designed to regenerate its capability to soften water.

With reference to Figure 2, water softener **10** preferably includes a source pipe **12**, connected to a source of hard water **14**, a destination pipe **16**, connected to a destination **18** intended to use the softened water, and a drain pipe **20** connected to a drain **22**. Pipes **12**, **16**, and **20** are also connected to a control valve **24**. A resin bed **26**, preferably comprising particles of ion exchange resin, is disposed in a resin tank **28**. A pipe **30** and a pipe **32** connect resin tank **28** to control valve **24**. A brine tank **34** holds a quantity of a regenerant salt **36**, typically NaCl or KCl, and is connected to an aspirator valve **38** by a pipe **40**. Pipe **40** includes a brine valve **42**. Pipes **44** and **46** connect aspirator valve **38** to control valve **24**. Control valve **24** may be configured to interconnect pipes **12**, **16**, **20**, **30**, **32**, **44**, and **46** in a number of different ways hereinafter described.

Water softener **10** preferably includes a micro computer controller **48** having a user interface **50**. User interface **50**, shown schematically in Figure 3, preferably includes an LCD display **60**, and various buttons, such as a "SELECT" button **62**, an "UP" button **64**, and a "DOWN" button **66**, to allow the user to selectively view and enter in information. A timer **52** is provided to enable controller **48** to measure time durations. A water meter **54** is placed in either pipe **30** or pipe **32** to enable controller **48** to measure the amount of water flowing through resin tank **28**. A temperature sensor **56** is preferably disposed in brine tank **34** to enable controller **48** to measure the temperature therein. Temperature sensor **56** is preferably a thermocouple or a semiconductor device. Controller **48** sets the configuration of control valve **24**.

When in service, hard water from source **14** passes through supply pipe **12** to control valve **24**, which is configured so that the hard water then flows through pipe **30** to resin tank **28**. In resin tank **28** the hard water passes through resin bed **26**, where it is softened by an ion exchange process. The soft water flows out from resin tank **28** through pipe **32** to control valve **24**. Control valve **24** is configured to direct the soft water from pipe **32** to pipe **16**, where it is directed to its destination **18**.

When the resin bed **26** loses its capacity to effectively soften the water passing through it, regeneration is necessary. The regeneration cycle preferably includes the following steps: (1) fill; (2) brine draw; (3) slow rinse; (4) backwash; and (5) fast rinse. During the fill step, a quantity of water flows into brine tank **34** to dissolve a quantity of the salt **36** therein in order to make the amount of brine necessary for regeneration. Specifically, control valve **24** is configured so that hard water from source **14** flows through pipe **12** to pipe **30** to resin tank **28**. The hard water passes

through resin bed **26** and flows out through pipe **32** to control valve **24**. Control valve **24** is configured to direct this water to pipe **44** and then to pipe **40** through aspirator valve **38**. Brine valve **42** opens in response to the flow of water in pipe **40**, allowing the water to enter brine tank **34**. The water filling brine tank **34** dissolves a quantity of the salt **36** to form a brine, whereby the brine is substantially saturated.. Temperature sensor **56** preferably measures the temperatures of the water and of the resulting brine. The duration of the fill step determines the amount of water that enters brine tank **34** and therefore the amount of regenerant salt dissolved and available for regeneration.

During the brine draw step, control valve **24** is configured so that hard water from pipe **12** is directed to pipe **44**, whereupon it flows through aspirator valve **38** to pipe **46**. This flow through aspirator valve **38** creates suction on pipe **40** by the Venturi effect. Brine valve **42** is open, so that the suction on pipe **40** draws the brine in brine tank **34** formed during the fill step, up into pipe **40**, which then flows through aspirator valve **38** to pipe **46**. Control valve **24** is configured so that the water and brine from pipe **46** are directed through pipe **30** to resin tank **28**. The brine entering resin tank **28** flows through resin bed **26**, thereby regenerating it, and flows out through pipe **32** as waste. The waste is directed to drain **22** via pipe **20** for its disposal. The duration of the brine draw step is sufficiently long so as to withdraw all or nearly all of the brine from brine tank **34**. Preferably, brine valve **42** closes automatically when the level of brine in brine tank **34** falls below a prescribed point.

During the slow rinse step, brine valve **42** is closed, and brine is no longer withdrawn from brine tank **34**. However, water keeps flowing as in the brine draw step. In particular, the configuration of control valve **24** is the same as for the brine draw step. The remaining brine continues to flow through resin bed **26** until replaced with incoming water in order to achieve

maximum ion exchange and to continue to flush out any hardness minerals or brine which may remain in resin tank **28**.

During the backwash and fast rinse steps, control valve **24** is configured so that hard water from pipe **12** is directed to pipe **30** and flows into resin tank **28**. The water flows out of resin tank **28** through pipe **32** and is directed to drain **22** via pipe **20**. During the backwash step, the water flows up through resin bed **26**, lifting up and expanding the resin bed **26** and flushing out iron minerals, dirt, sediments, hardness minerals, and any remaining brine. During the fast rinse step, a fast flow of water is directed downward through resin bed **26** to pack it and prepare it for service.

Controller **48** determines when to regenerate resin bed **26** and to what capacity. Various methods may be used for these determinations, such as those described in U.S. Patent Nos. 5,544,072 and 4,722,797. The necessary capacity will, in general, depend on the hardness of the water to be treated. User interface **50** therefore preferably includes means by which the user can enter the water hardness, expressed in grains per gallon, into controller **48**. To accommodate the use of different types of regenerant salt, user interface **50** also enables the user to specify the type of salt used, e.g., whether NaCl or KCl is used.

Preferably, the user-adjustable parameters, which typically include the time of day for regeneration, the water hardness, and the type of regenerant salt used, are shown as various "screens" on display **60**, with each parameter having its own screen. At each screen, the user is able to scroll up and down through the available values for the parameter by pressing "UP" button **64** and "DOWN" button **66**, respectively. The user indicates the desired value for the parameter by pressing "SELECT" button **62**, whereupon the value is stored by computer controller **48** and the next "screen"

is shown on display **60**. In this way, the user is able to scroll through the available salt types, such as NaCl and KCl, and to make a selection. Other means for indicating the regenerant salt type, such as other types of computer interfaces or mechanical switches, could also be used.

From the desired capacity to which resin bed **26** is to be regenerated, the required salt dose may be determined from empirical data as described above. The salt dosages, D, for each desired regenerated capacity, C, are programmed into controller **48** for the various salt types intended to be used, such as NaCl and KCl. Thus, from the type of salt used and the regenerated capacity required, controller **48** is able to determine the salt dosage, D, needed for regeneration.

The value of D, the salt dosage, determines the amount of water that must be supplied to brine tank **34** during the fill step, based on the solubility of that salt. Preferably, the amount of water added during the fill step is determined by the fill time, the flow rate being a fixed quantity. The required fill time may thus be calculated as follows:

$$F = D/(R \times S)$$

where F = fill time in minutes, D = the salt dosage in pounds, R = the fill rate in gallons per minute, and S = the solubility of the salt in pounds per gallon. When KCl is used as the regenerant salt, however, an added complication arises in that its solubility is markedly temperature dependent over the typical range of water temperatures encountered, namely, 34° F to 80° F, whereas the solubility of NaCl is relatively constant over this range. In particular, the solubilities of NaCl and KCl are both approximately 2.99 lbs./gal. at 80° F. At lower temperatures, the solubility of KCl is significantly less than that of NaCl as summarized in Table 1. The information in Table 1 has been generated from empirical data linearized in the range of 34° F to 80° F, with the solubility of NaCl taken to

be a constant 2.99 lbs./gal. The data of Table 1 is representative only, in that results can be affected by the water chemistry in the particular application.

TABLE 1

Temp. (°F)	KCl Solubility (lbs./gal.)	KCl/NaCl Difference (%)
34	2.35	27.2%
36	2.38	25.7%
38	2.40	24.2%
40	2.43	22.8%
42	2.46	21.4%
44	2.49	20.1%
46	2.51	18.8%
48	2.54	17.5%
50	2.57	16.2%
52	2.60	14.9%
54	2.63	13.7%
56	2.65	12.5%
58	2.68	11.4%
60	2.71	10.2%
62	2.74	9.1%
64	2.76	8.0%
66	2.79	5.9%
68	2.82	5.9%
70	2.85	4.9%
72	2.88	3.8%
74	2.90	2.8%
76	2.93	1.9%
78	2.96	0.9%
80	2.99	0.0%

To accommodate the use of KCl, the fill times should be adjusted on the basis of water temperature to reflect the temperature dependent solubility of KCl. The simplest approach to account for this effect is not to measure the actual water temperature at all but to simply assume a typical water temperature and to increase accordingly the fill time for KCl by a fixed percentage relative to the fill time that would be required if NaCl were used. An increase in the fill time of 25% is found to be a reasonably adequate approximation for the most typical water temperatures encountered.

A more accurate system includes temperature sensor **56** in order to enable controller **48** to determine the temperature of the water being supplied to brine tank **34**. Temperature sensor **56** is preferably located in brine tank **34** but may alternatively be located upstream, such as in source pipe **14**. Controller **48** is programmed with the solubilities of KCl at various water temperatures, so that when KCl is used as the regenerant salt controller **48** measures the water temperature and sets the required fill time accordingly.

Alternatively, the water temperature may be a user-adjustable parameter entered into computer controller **48** by means of user interface **50** as previously described.

The temperature of the brine formed in brine tank **34** does not remain constant during the course of the fill. An example of how the brine temperature changes during the course of a fill when KCl is used as the regenerant salt is shown in tabular form in Table 2. This temperature changed is caused by two factors. First, before the fill begins, the temperatures of the water and of brine tank **34** with dry regenerant salt **36** present within will not in general be equal, so that the brine temperature will naturally equilibrate during the course of the fill. Second, the dissolution process

of the salt also changes the temperature of the brine. In particular, the dissolution of KCl is significantly endothermic, so that the dissolution process itself cools the brine.

The temperature change of the brine during the course of the fill thus presents an added difficulty in the case of KCl because of its temperature dependent solubility. Temperature sensor **56** should thus measure the temperature during the course of the fill, preferably at regular intervals such as every minute. Typical results under this method are tabulated in Table 2.

TABLE 2

Fill Time (Min)	Sample Temp (°F)	Solubility (lbs/gal)	Required Fill Water (gal)	Required Fill Time (min)
0	60	2.7048	2.219	7.40
1	56	2.6492	2.265	7.55
2	52	2.5937	2.3133	7.71
3	48	2.5381	2.3640	7.88
3	48	2.5103	2.3902	7.97
5	44	2.4826	2.4168	8.06
6	42	2.4548	2.4442	8.15
7	41	2.4409	2.4581	8.19
8	40	2.4270	2.4722	8.24
8.24	---	END OF	FILL	---------

The adjustment in water volume to add to the brine tank to account for the difference in solubility of potassium chloride at different temperatures is as is found in Table 1. Based on Table 1, the average change in solubility (pounds of salt per gallon of water) of KCl is 0.014 pounds

per gallon per "minus" degree Fahrenheit over the range of 80°F to 34°F. Thus, the KCl solubility, in pounds per gallon, is related to the temperature of the brine solution as follows:

$$\text{KCl solubility} = 2.99 - (80 - \text{brine temperature})(0.014)$$

To determine the water volume equivalency (i.e., the gallons of water to add to obtain one pound of KCl in solution as compared to the amount of water to obtain one pound of NaCl in solution, at a temperature) the relationship is NaCl solubility ÷ KCl solubility at the temperature. Thus, the water volume equivalency of KCl is 1.27234 @ 34°F, 1.23045 @ 40°F, 1.16342 @ 50°F, 1.10332 at 60°F, 1.04912 @ 70°F, and 1.0000 at 80°F.

Based on the above, the water adjustment rate for temperature, sometimes referred to as WARFT, (additional percentage of water required for equivalent KCl in solution per degrees below 80°F) is 0.592% more water per degree over the temperature range of 80°F to 34°F; calculated by change in water equivalency rate over the temperature range divided by the temperature difference, i.e., (1.27234 - 1.0000) ÷ 46. Additional adjustment rates over different temperature ranges, as determined from the data, are: 0.49% for the range 80° to 70°; 0.52% for the range 80° to 60°; 0.55% for the range 80° to 50°; and 0.58% for the range 80° to 40°. Each of these rates is the percent increase in water required, that is, in addition to the water determined for a brine solution at 80° F, for each °F the brine temperature is below 80°F. Thus, it is believed that good results can be obtained if the water volume is adjusted at a rate in the range of 0.49% to 0.59% per °F difference, and the preferred range is 0.55% to 0.58% per °F difference. Accordingly, if the temperature in the brine tank is 40°F, the amount of water to be added to the brine tank should be increased by about 23.2% (determined by adjustment rate of + 0.58 % /°F, times a temperature difference of 40°) in addition to the amount of water which would be added if the temperature were at 80°F.

Additionally, the data in Table 1 shows that the rate of water adjustment for temperature differences for potassium chloride is substantially linear in the range of temperatures ordinarily expected for the brine, and has been found to be directly related to the water temperature as follows: the rate equals [0.488 + 0.0029 (70 - brine temperature)] ÷ 100, which equals (6.91 - .029 brine temperature) 10^{-3}. As an example, using this relationship to determine the water adjustment rate for brine solution at 60°F, the rate equals [0.488 + 0.0029 (70 - 60)] ÷ 100, i.e., 0.00517 increase per degree of brine temperature difference from 80°F, and at 34°F the rate is [0.488 + 0.0029 (70 - 34)] ÷ 100 = 0.00592 increase in water per degree of brine temperature difference from 80°F. These rates can be used to determine a water adjustment adder, which is WARFT times (80 - temperature of brine solution), and a water adjustment multiplier which is 1 + water adjustment adder. Thus water adjustment rates and multipliers, based on the above relationships are as follows:

Brine Temperature	Water Adjustment Rate	Water Adjustment Multiplier
34°	0.00592	1.27232
40°	0.00575	1.23000
50°	0.00546	1.16380
60°	0.00517	1.10340
70°	0.00488	1.04880

Referring now to Table 2, the required fill time is directly related to the volume of water desired. In the example of Table 2, the fill rate is 0.3 gallons per minute. With a constant fill rate, the brine fill time determines the volume of water added to the brine tank, and the amount of the salt that can be in solution. The fill time can be adjusted according to the same water adjustment

multiplier set forth above to obtain the desired quantity of water in the brine tank and a desired amount of KCL in solution, i.e., the brine, and which will be available to be delivered to the resin bed for regeneration. For example, if six pounds of KCL were to be delivered to the resin bed for regeneration, the volume of water to be delivered to the brine tank at 80°F would be about 2.00 gallons and the brine fill time would be 6.666 minutes at a water delivery rate of 0.3 gallons per minute. If the brine temperature were 40°F, the water adjustment rate would be about 0.00575% increase per degree of temperature difference from 80°F, which temperature difference is 40°, thus, the water adjustment adder is .00232, i.e., 23.2% for a water adjustment multiplier of 1.23. Using that adjustment, the volume of water required @ 40°F is about 2.46 gal. (2.000 @ 80° + 2.000 x 0.23) and the brine fill time is about 8.2 minutes (6.666 + 6.666 x 0.23). Both of which compare favorably with 2.4722 gal. and 8.24 minutes as shown in Table 2.

The volume of water for the brine fill for KCL can be determined from the following relationships:

$$\text{Water To Brine Tank (gallons)} = \frac{\text{Salt}}{\text{Salt Solubility}} (1 + \text{WARFT} \times dT)$$

Thus the gallons of water required at a brine temperature of BT is

$$\text{Gallons of Water} = \frac{\text{Salt}}{\text{Salt solubility}} (1 + [0.488 + 0.0029 (70 - BT)](80 - BT))\ 10^{-2}$$

which for potassium chloride equal salt $(519.2 - 3.086BT + 9.6(BT)^2\ 10^{-3})\ 10^{-3}$

and

$$\text{Brine Tank Fill Time (minutes)} = \frac{\text{Salt } (1 + \text{WARFT} \times dT)}{\text{Salt Solubility} \times \text{WDR}}$$

which for potassium chloride equals:

$$= \frac{\underline{\text{Salt}}\,(519.2 - 3.086BT + 9.6((40)^2\,10^{-3})\,10^{-3}}{WDR}$$

Wherein:

Salt = pounds of KCl salt desired for regeneration of resin bed.

Salt Solubility = solubility at 80°F, which is 2.99 lbs/gal for KCl

WARFT = water adjustment rate for temperature (increase per degree below 80°)

dT = temperature differential between brine temperature and 80°F

WDR = water delivery rate to brine tank (gallons per minute)

BT = temperature of the brine.

Based on the results of Table 2, it can be seen that an additional quantity of water in the brine tank is required to dissolve equivalent amounts of potassium chloride depending upon the brine temperature, for example about 11% more at 60°F (0.219 ÷ 2.00) and about 16% more at 52°F (0.3133 ÷ 2.00) and about 24% more at 40°F (0.4722 ÷ 2.00). This increased water allows an amount of potassium chloride to be present in the brine which is substantially equivalent to the amount of sodium chloride which would be present in an amount of brine without the additional water.

Also note from Table 2 that the final brine temperature is approximately 20 degrees lower than the temperature at the start of the fill, i.e., the temperature started at 60°F and ended at 40°F. Thus, the temperature selected for determining the water adjustment rate and the water adjustment factor should be about 20° less than the temperature of the water admitted to the brine tank. If the temperature of the source water is used to determine the water adjustment rate and multiplier, the

relationship discussed above would be adjusted for that 20° difference by substituting (source water temperature - 20) for brine temperature which results in the relationships:

$$WARFT = (6.91 - (.029[SWT-20])\ 10^{-3}$$

$$=(7.49 - .029\ SWT)\ 10^{-3}$$

where SWT = source water temperature, and

Water Adjustment Multiplier

$$= 1 + WARFT \times dT$$

$$= 1 + (6.91-[.029(SWT-20)])\ 10^{-3}\ (dT)$$

$$= 1 + (7.49 - .029\ (SWT))\ 10^{-3}\ (100 - SWT)$$

$$= 1 + [.749 + 2.9\ (SWT)^2\ 10^{-5} - .01039\ SWT]$$

The KCl Water Volume Equivalency (WVE) is based on the KCl Solubility presented in Table 1. The KCl Water Volume Equivalency at a given brine temperature is the gallons of water to obtain the amount of KCl in solution which is equal to an amount of NaCl in solution. It can be determined from Table 1 by dividing the NaCl Solubility (2.99 pounds per gallon of water) by the KCl solubility (see second column of Table 1 for soluability at different temperatures). Thus at 40° the KCl Water Volume Equivalency is 2.99 ÷ 2.43 = 1.230 gallons of water for KCl to have the same amount of KCl in solution as one gallon of NaCl solution. Accordingly, the KCl Water Volume Equivalency at various temperatures is as follows:

Temp (°F)	KCl Water Volume Equivalency
34	1.272
40	1.230

50	1.163
60	1.103
70	1.049
80	1.000

which are stated above as the Water Adjustment Multipliers.

The KCl Water Equivalency values can be used to determine the KCl water volume desired, based on the temperature of the brine. To do so, KCl Water Equivalency is plotted against Brine Temperature, as shown in FIG. 4. The KCl Equivalency can be determined at each temperature from the relationship between the KCl Equivalency and Brine Temperature, which relationship is determined from the slope of the plot of the points; which relationship is KCl Water Volume Equivalency = 1.103 + 0.0065 (60° - Brine Temperature) in the temperature range from 60° to 34°. That relationship also closely approximates the KCl Water Volume Equivalency in other selected temperature ranges. These relationships can also be stated as formulas with other numerical factors for different temperature ranges and "curves" believed to be the best "fit" to the plotted values.

Further, the Water Adjustment Rate (WAR) for KCl, as set forth above, is determined from the data in Table 1 and Table 2. The WAR is based on the additional water needed to put equal amounts of KCl in solution, i.e., equal to the amount of NaCl which is desired if NaCl were to be used. The WAR is the percent increase in water per change of temperature of the brine solution from the standard temperature of 80°F; 80°F was selected because the solubility of KCl is substantially the same as the solubility of NaCl at that temperature, i.e., 2.99 lbs. per gallon (see Table 1), and then varies from the solubility of NaCl when the brine temperature is cooler than 80°F as shown in Table

1. Using 40°F as an example the WAR for KCl can be determined by calculating the extra water required to put an equivalent amount of KCl in solution at 40°, which is the KCl Water Volume Equivalency of 1.230 gallons minus the amount of water for NaCl which is 1.000 gallon. The result is 0.230 gallons extra water required at 40°. The difference in temperature from the standard is 40° (i.e., 80° - 40°). Thus the WAR for brine temperature at 40° is 0.230 gallons ÷ 40° = 0.00575 gallons/degree difference from 80° and its units are increased percent volume of water per degree of temperature. WARs for selected other temperatures, determined in the same manner as above, are as follows:

Brine Temp (°F)	Water Adjustment Rate
34	0.00592
40	0.00575
50	0.00546
60	0.00517
70	0.00488
80	- 0 -

These values can be plotted as shown in FIG. 5. And the relationship between the WAR for KCl and Brine Temperature can be determined from the plot, by well known algebra analysis, to be WAR for KCl = [0.488 + 0.0029 (70 - Brine Temperature)] ÷ 100, for brine temperatures in the range of 60° to 34°. Thus, the relationship set forth above (i.e., the rate of water adjustment for temperature differences for potassium chloride is substantially linear in the range of temperatures ordinarily expected for the brine, and has been found to be directly related to the water temperature as follows:

the rate equals [0.488 + 0.0029 (70 - brine temperature)] ÷ 100, which equals (6.91 - .029 brine temperature) 10^{-3}) is derived from Table 1.

The preferred method of using KCl as the regenerant is described as follows. At regular time intervals during the fill, the temperature at temperature sensor **56** is measured. From this temperature, the solubility of the salt is calculated, and from this value the required volume of fill water and ultimately the required fill time may be calculated, as shown in Table 2. The fill then proceeds until the required fill time is approximately equal to the actual fill time.

Even after the fill ends, the brine temperature is often observed to continue to drop when KCl is used. This may be due to the dissolution rate of KCl which is less than that of NaCl. In other words, the KCl continues to dissolve even after the flow of water stops, thereby cooling the brine even further. The temperature drop is observed to be fairly small -- typically 2° F. The temperature drop reduces the solubility of KCl even further, so that less dissolved KCl is present in the brine as result. The way to compensate for this effect is to add more water during the fill step by increasing the fill time. Typically, a 1% increase in the fill time is all that is required.

When the fill time is adjusted, the brine draw time must also be adjusted to ensure that the required amount of brine is withdrawn from brine tank **34**. Typically, the ratio of the brine draw time to the fill time is a fixed quantity, so that the brine draw time may be taken to be the fill time multiplied by this quantity. The slow rinse time is typically fixed. Preferably, controller **48** calculates the necessary brine draw time based on the fill time actually used. The total "brine time" is then the sum of this necessary brine time and the slow rinse time. Controller **48** maintains control valve **24** in the brine draw/slow rinse configuration for this "brine time" to ensure that the required amount of brine is withdrawn. In the case where the fill time for KCl is increased by 25% relative

to NaCl, a corresponding increase in the "brine time" for KCl of approximately 12.5% relative to NaCl is found to be sufficient.

The above described embodiments are merely illustrative of the features and advantages of the present invention. Other arrangements and advantages may be devised by those skilled in the art without departing from the spirit and scope of the present invention. Accordingly, the invention should not be deemed to be limited to the above detailed description but only by the claims that follow.